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Westinghouse Astronuclear Laboratory

PCV-41 PRESSURE CONTROL SYSTEM,
EXPERIMENTAL CHECKOUT AND SUBSEQUENT ANALYSIS (U)

MASTER

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SUMMARY

Prior to the facility checkout testing, an analysis and analog computer study of the PCV-41 Pressure Control System was conducted. The results of this analysis and study were used to design the original controller compensation and to predict the operation of the system when it was tested. During the facility checkout series and EP-IA prime of the NRX/EST test series, data on the PCV-41 Pressure Control System was obtained. This data was used to validate the analog computer simulation of the PCV-41 system and to adjust the PCV-41 Pressure Control System compensation.

The initial analysis and analog computer study of the PCV-41 Pressure Control System are reported in WANL-TME-1270.

Based on the analysis of system checkout data and analog computer studies, the following compensation was recommended:

$$\frac{\alpha_d}{P_e} = \frac{.071 (1 + .25S)}{S (1 + .01S)} \quad \frac{\% \text{ Open}}{\text{psia}}$$

α_d = PCV-41 valve opening demand

P_e = Difference between demanded nozzle torus pressure and measured nozzle torus pressure (feedback pressure)

The nozzle torus pressure demand signal to be used in the event of a flow shutdown is:

$$P_d = A + .4 A e^{-.5t} \text{ psia}$$

The amplitude of the pressure demand signal, A , is determined by the station 26 temperature at the instant the flow shutdown occurs.

Analysis of analog computer flow shutdown experiments by Aerojet-General Corporation and WANL showed that the PCV-41 Pressure Control System would meet the reactor and nozzle requirements for protecting the test article during a flow shutdown.

FACILITY CHECKOUT RESULTS

Four facility checkout tests were conducted in preparation for the NRX/EST test series. During three of these tests dynamic response data on the PCV-41 pressure control system were obtained. In addition to dynamic data, flow shutdown data were obtained.

Based on the initial analysis and analog computer study of the PCV-41 pressure control system (TME-1270) the following compensation was installed in the PCV-41 pressure control loop for EP-I-FC:

$$\frac{\alpha_d}{P_e} = \frac{.1 (1 + S)}{S (1 + .01S)} \quad \frac{\% \text{ Open}}{\text{psia}}$$

Figure 1 is a comparison of the dynamic characteristics predicted by the analog computer and the results of frequency response data obtained during EP-I-FC. The data indicates that the actual system contains more phase shift than predicted by the analog computer model of the system. The test data were obtained by oscillating the PCV-41 system in flow control. The results plotted in Figure 1 were obtained by reducing the open loop data received and incorporating the controller dynamics to obtain the PCV-41 pressure control system response.

During the frequency response measurements of EP-I-FC the reactor impedance simulator valve (AVV-11) was fluctuating. This valve was installed in such a manner that movement during the frequency response measurements appeared as a positive feedback signal

in the PCV-41 control loop. Since the feedback signal in the PCV-41 pressure control system should be negative, the data obtained during EP-I-FC was not valid.

Even though the closed loop data obtained during EP-I-FC were in error, it was possible to determine the characteristics of the PCV-41 system by examining the system open loop data. An analysis of the open loop data (Figure 1) indicated that the physical system contained more phase shift than predicted by the analog computer model. In order to increase the margin of stability in the system, the control loop compensation for EP-IA-FC was changed to:

$$\frac{a_d}{P_e} = \frac{.1 (1 + .25S)}{S (1 + .01S)} \quad \frac{\% \text{ Open}}{\text{psia}}$$

Results of the frequency response measurements taken during EP-IA-FC are shown in Figure 2. For this test the reactor impedance simulator valve (AVV-11) was installed so that the feedback signal to the PCV-41 pressure control system was negative. Figure 2 shows that the system has even more phase shift than predicted by EP-I-FC.

The final dynamic check of the PCV-41 pressure control loop was made during EP-III-FC. For this test the reactor impedance simulator valve (AVV-11) was replaced by an orifice. This change was necessary due to poor operating characteristics of the AVV-11 valve during the previous facility checkouts. When used, the AVV-11 valve showed a tendency to leak gas and could not be maintained at a constant position. In order to increase the margin of stability, the PCV-41 pressure control loop compensation was changed to:

$$\frac{a_d}{P_e} = \frac{.071 (1 + .25S)}{S (1 + .01S)} \quad \frac{\% \text{ Open}}{\text{psia}}$$

Analog computer predictions and test results of EP-III-FC are shown in Figure 3. The results show that the phase displacement was as predicted but the gain was lower than predicted. Figure 3 shows an 8 db open loop gain difference between the analog computer predictions and the EP-III-FC test results. This gain difference indicates that the facility changes made between EP-IA-FC and EP-III-FC resulted in a lower PCV-41 system loop gain.

When the data from EP-IA-FC and EP-III-FC are normalized to a common base, the data shows the same differences as Figure 3. The normalized data is plotted on Figure 4. This plot shows a difference in system open loop gain of 6 to 8 db. This difference can only be explained by the changes in the physical system between EP-IA-FC and EP-III-FC. Two significant changes were made in the system between the two tests, the reactor impedance simulator valve (AVV-11) was replaced by an orifice and the body of the PCV-41 valve was replaced.

In order to normalize test data the open loop gain of the system must be adjusted to a common tank farm pressure. As the gaseous hydrogen tank farm pressure increases, the gain of the PCV-41 valve increases. Figure 5 shows the variation of the PCV-41 valve gain with tank farm pressure.

NRX/EST - EP-IA PRIME RESULTS

During the first EP of the NRX/EST test series a dynamic check of the PCV-41 pressure control system was conducted. This test was necessary to ensure that changes in the physical system had not affected the dynamic characteristics of the PCV-41 pressure control system.

Figure 6 is a plot of the frequency response data obtained during NRX/EST-EP-IA prime. This data is in good agreement with the data obtained during EP-III-FC. Figure 7

is a Bode plot of the frequency response data obtained during EP-IA prime. In addition to frequency response measurements, step response tests were conducted during EP-IA prime. The results of digital reduction of this data are plotted in Figure 8 and 9. A comparison of Figures 7, 8 and 9 shows that the various tests produce the same system response.

MODEL VALIDATION AND ANALYSIS

One of the prime objectives of the PCV-41 checkout tests was to obtain data so that an accurate analog computer simulation of the PCV-41 system could be developed. The accuracy of the analog computer model was very important because it was not possible to conduct a flow shutdown in the EST mode during the facility checkout tests. Therefore, all flow shutdown studies in the EST mode of operation were conducted on the analog computer. The method used to validate the analog computer model of the system was to perform the same tests on the computer as were conducted on the facility and compare the results.

Figure 10 is the result of frequency response measurements conducted on the analog computer model of the PCV-41 pressure control system. Comparing Figures 10 and 7 shows that the analog model of the system is an accurate description of the physical system.

Predictions of the system operation by the analog computer will be accurate and can be used to determine if the control system satisfies the requirements for protection of the test article.

Analog computer studies of an EST shutdown from rated power conditions were conducted to determine if the PCV-41 pressure Control system satisfied the design requirement of 22 pounds per second minimum flow through the nozzle tubes. These studies were con-

ducted on a single console model of the PCV-41 pressure control system. This model^{2,3} uses a constant impedance to simulate the reactor. The compensation used for this study was:

$$\frac{a_d}{P_e} = \frac{.071 (1 + .25S)}{5 (1 + .01S)} \frac{\% \text{ Open}}{\text{psia}}$$

A tank farm pressure of 3000 psia and initial nozzle torus pressure demand signal of:

$$P_d = 660 + 236 e^{-2t} \text{ psia}$$

were used for this study.

The analog computer studies indicated that the system, with the compensation used during EP-III-FC, would not meet the nozzle flow requirement. It was decided that the compensation should not be changed unless absolutely necessary since it had been experimentally tested and found to be stable. Another method of changing the transient response of the system without changing the basic system equation is to change the input or demand signal to the system. Studies were conducted to determine if the demand signal could be changed enough for the system to satisfy the nozzle flow requirement. The results of the studies indicated that a demand signal of:

$$P_d = 660 + 260 e^{-.5t} \text{ psia}$$

for a full power EST flow shutdown would satisfy the system requirements. This pressure demand signal can be written for all initial conditions as:

$$P_d = A (1 + .4 e^{-.5t}) \text{ psia}$$

The amplitude, A, of the pressure demand signal is determined by the average station 26 temperature at the time of the flow shutdown. The PCV-41 nozzle torus pressure demand as a function of average station 26 temperature is shown in Figure 11.

Subsequent to this analysis the nozzle tube flow requirements for a full power shutdown were modified. Additional analog computer studies of the PCV-41 pressure control system were conducted to determine:

1. If the pressure control system satisfies the updated nozzle tube flow requirement of a minimum 23.5 lbs./sec. flow for the first 2.5 seconds after a flow shutdown from full power conditions.
2. The variation of system performance with tank farm pressure.
3. The operation of the PCV-41 system at various points on the engine operating map.

In order to satisfy the revised nozzle tube flow requirement for a full power flow shutdown, the PCV-41 pressure control system compensation was changed to:

$$\frac{a_d}{P_e} = \frac{.224 (1 + .25S)}{S (1 + .01S)} \quad \frac{\% \text{ Open}}{\text{psia}}$$

With this compensation it was determined that the system would satisfy the nozzle tube full power flow shutdown requirements for all tank farm pressures above 2000 psia. Tests of the PCV-41 system, with the above compensation, at various points of the operating map revealed that the combination of control system response time and time varying pressure demand signal resulted in undesirable flow spikes for shutdowns from low chamber temperatures and pressures. To eliminate the flow spikes the pressure demand signal was changed to:

$$P_d = A + B e^{-.5t} \text{ psia.}$$

Where A is the slaving curve shown in Figure 11 and B is the slaving curve shown in Figure 12. Analog computer tests of the system with the above pressure demand signal and control system compensation indicated that the PCV-41 pressure control system would meet the modified nozzle flow rate requirement and operate satisfactorily around the reactor operating map.

At the same time as the above analog studies were being conducted, Aerojet-General Corporation (AGC) was continuing to evaluate previous analog computer results. The analog studies being evaluated used the controller compensation of:

$$\frac{a_d}{P_e} = \frac{.071 (1 + .25S)}{S (1 + .01S)} \quad \frac{\% \text{ Open}}{\text{psia}}$$

and the pressure demand signal of:

$$P_d = A (1 + .4 e^{-.5t}) \text{ psia.}$$

Results of the AGC evaluation noted that the nozzle tube coolant flow rate for a full power flow shutdown was in violation of the updated nozzle flow criteria. However, the period of time during which the flow rate was inadequate and the margin by which it was inadequate were both sufficiently small that the risk of damage to the nozzle coolant tubes was acceptable if the tank farm pressure (P-011) was maintained at a minimum of 3000 psia. It was desirable to use the above controller compensation since it had been checked out experimentally during the EST facility checkouts. Therefore, a modification in the tank farm system was made to insure the required pressure at P-011.

SYSTEM EVALUATION

The open loop transfer function of the PCV-41 pressure control system is:

$$G(S) = \frac{2.58 (1 + .25S)}{S (1 + .01S) (1 + .04S) (1 + .006S) (1 + .23S) \left[\left(\frac{S}{94} \right)^2 + \frac{1.2}{94} S + 1 \right]}$$

A comparison of the dynamic response of this function with system test data indicates that for all practical purposes they are identical.

Since the mathematical expression for the control system is known, a root locus of the system can be plotted. Figure 13 is a plot of the PCV-41 pressure control system root locus for a tank farm pressure of 3000 psia. This locus can be used to evaluate the system response from a control theory viewpoint.

The locus shows that the dominant closed loop poles of the system are located on the real axis at a value of approximately 10 radians per second. For this closed loop pole location the damping ratio of the system is greater than 1. Systems with a damping ratio greater than 1 are classified as overdamped systems. These systems exhibit zero overshoot to a step input demand and have a long rise time.

Another indication of system response is given by the system velocity constant. The velocity constant for this system is 2.58/second. This means that for a ramp demand signal of 1 psia per second the system would have a steady state error of .388 psia.

The root locus shows that the system gain may be increased to improve the system response and still maintain an acceptable margin of stability. If the gain of the system is increased by a factor of 2.5, the damping ratio will be decreased to .707 and the velocity constant will be increased to 6.45/second. This would result in a much faster system response and a smaller steady state error to a ramp input. With this increase in gain the steady state error to a 1 psia per second ramp demand signal would be .155 psia.

CONCLUSION

An analog computer model of the PCV-41 pressure control system was developed from the system checkout test data. This analog model of the system was used to design the PCV-41 pressure control system compensation and to predict system performance in the event of a flow shutdown during the NRX/EST test series.

Analog computer studies of PCV-41 system show that the PCV-41 pressure control system will protect the test article in the event of a flow shutdown.

FIGURE 2

PCV-41 Dynamic Response

Pressure Measured

Pressure Demand

NRX/EST EP-IA-FC Frequency Response Data

Compensation: $\frac{a_d}{P_e} = \frac{.1 (1 + .25S)}{S (1 + .01S)}$ $\frac{\% \text{ Open}}{\text{psia}}$

Tank farm pressure = 2625 to 2240 psia

Frequency in Radians/sec.

FIGURE 5

PCV-41 Valve Gain Versus Tank Farm Pressure

Figure 6

NRX/EST EP-1A Prime Frequency
 Response Data - PCV-41 Pressure Control System
 Pressure Measured
 Pressure Demand
 Compensation: $\frac{\Delta d}{P_e} = \frac{.071 (1+.25S)}{S (1+.015S)} \frac{\% \text{ Open}}{\text{PSIA}}$
 Tank Farm Pressure = 3000 PSIA
 Frequency in Radians/Sec

FIGURE 11
Slaving Curve for Nozzle Torus Pressure Demand
Signal

FIGURE 12
Slaving Curve for Supplement to Nozzle Torus
Pressure Demand Signal

FIGURE 13
ROOT LOCUS OF PCV-41 PRESSURE CONTROL SYSTEM
FOR 3000 PSIA TANK FARM PRESSURE